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Paralysis Caused by Working Under Compressed Air in Sinking the Foundations of Londonderry New Bridge. By T. H. Babington, M.D, Surgeon Londonderry County Infirmary; and A. Cuthbert, M.D., Medical Officer Glendermott Dispensary, Londonderry.

The new bridge recently erected over the river Foyle, at Londonderry, is an iron structure, nearly 1,300 feet long, consisting of two platforms or roadways—the lower for railway traffic; the upper, a carriage way, with footpaths for passengers and ordinary traffic. The whole structure is supported on 16 cast iron cylinder piles, placed in pairs, 35 feet apart, at intervals of 119 feet. Resting on the centre cylinder there is a swing-bridge, which is opened and closed for navigation. Each cylinder is 11 feet in diameter; $1\frac{1}{2}$ inch thick; and, when sunk to the proper foundation, was filled with concrete, composed of sand, gravel, and cement. The centre cylinder supporting the swing bridge is 30 feet in diameter; and rests on seven smaller ones, 8 feet in diameter. These cylinders were all sunk to solid foundations before being filled with the concrete; and these foundations were obtained at various depths—the greatest depth 75 feet from the surface of the water,[a] and 40 feet below the bed of the river.

[a] In the London Times for July 7, 1859, we find the following notice of a bridge built on the Nile :—

"The Kaffre Azzyat Bridge.—This important, malleable, iron girder beam-bridge across the Nile, is nearly 1,400 feet long; has 11 openings—2 of which are 104 feet each; and spanned by a swing beam. The centre of the swing rests upon a foundation pier, composed of 6 pillars of 10 feet diameter each; and the remaining 11 foundation piers are of 2 pillars each, 10 feet diameter. These 28 foundation pillars were sunk by compressed air, on Mr. John Hughes' principle, to an average depth of nearly 60 feet below the bed of the river, and to 85 feet below high water. The internal pressure on the caissons, while sinking, ranging from 20 lb. up to 34 lb. on the square inch, in accordance with the depth of the ground and the height of the Nile."

It is obvious that to sink these cylinders, and to effect the excavation at such a depth, was a work of no ordinary difficulty. The workmen were to be got into, and out of, the cylinders; the cylinders were to be kept empty of water; excavations were to be carried on; the contents of the cylinder, earth, stones, &c., to be removed; and the concrete for filling to be introduced. All these objects were accomplished under the direction of Mr. Hughes, the able and indefatigable resident engineer, by the same means and machinery which he had first successfully used in sinking the foundations of the bridge over the Medway, at Rochester, and afterwards at Chepstow, and at the viaduct at Saltash. A detailed account of the plans adopted at Rochester is to be found in the tenth volume of *The Proceedings of the Institution of Civil Engineers* for May 13, 1851, in a paper by Mr. Hughes, entitled "The Pneumatic Method adopted in Constructing the Foundation of the New Bridge on the Medway, at Rochester. By John Hughes, C.E." We are indebted to, and beg to thank, Mr. Hughes, for kindly placing all his papers at our disposal.

The idea carried out was to give each cylinder the character of a diving bell during the operation of excavating and removing the materials from the interior, and filling in the concrete. Each cylinder was to be kept free from water, to enable the workmen to excavate until the cylinder was sunk to its proper foundation, and all the matters promptly removed from the interior; and the cylinder should be made to descend vertically.

To carry out these objects—that is, to sink the cylinder to its proper foundation—to excavate the interior—to keep the cylinder dry and free from water—and to remove the contents and introduce the concrete for filling, Mr. Hughes designed an apparatus as follows:—One of the cylinders—7 feet in diameter, and 9 feet long—was fitted with a wrought iron cover, securely bolted to it; through this cover 2 cast iron chambers, called air locks, projected $2\frac{1}{2}$ feet below the top of the cylinder, and 3 feet 9 below the cover—D shaped, with a sectional area of 6 square feet; the top of each air lock was provided with a circular opening, 2 feet in diameter, with a flap working on a horizontal hinge, which served to close it hermetically when the cylinder was filled with compressed air. The communication from the chamber to the inside of the cylinder was through a rectangular opening, 2 ft. by 3 ft. 4 in., on the flat side of the chamber, and had an iron door working on vertical hinges, to close it hermetically when required. The flap was analogous in

its use to the lower gate of a canal lock, and the door to the upper gate. The air locks were furnished with cocks communicating from the cylinder to the chamber, and from the chamber to the atmosphere. Each lock had two sets of cocks—one accessible from the inside of the chamber, for the use of men passing into and out of the cylinder; the other for use in passing buckets through the air locks. One cock, communicating between the chamber and atmosphere, was in charge of a man inside the cylinder, who, having closed the door, could let off compressed air, and so pass a bucket from within to the outside; another communicating from the interior of the cylinder to the chamber, was worked by a man outside, who had power, on closing the flap, to fill the cylinder with compressed air, and to pass a bucket from the outside to the inside. Light was admitted by lenses, and candles were burned at the bottom. Compressed air was supplied to the pile by a double-acting pump, with 2 barrels, 12 inches in diameter, and 18 inches stroke, driven by a 6-horse power non-condensing engine; the air supply pipe was $2\frac{1}{2}$ inches in diameter. The pumps being set in motion, the flap of one of the air locks, and the door of the other, were closed; a few strokes compressed the air within the pile sufficiently to seal the joints; and every subsequent stroke delivered an additional quantity, until the density was sufficient to expel the water (either underneath the cylinder or through a syphon) and leave the bottom dry. Whilst the pumping was in progress the men passed through the air locks to their places—each man dropped into one of the air locks, of which the flap was open; this he closed with one hand, and with the other opened the cock which admitted compressed air from the pile into the air lock. As soon as equilibrium was established between the two, the door opened with the slightest force, and the man stepped on the stage within the cylinder. A man could pass from the inside of the pile to the outside by the same lock, by closing the door and opening the cock communicating with the atmosphere.

The men worked under variable pressure—in some instances 27 or 28 lb. to the square inch; in others, as high as 35 and 38 lb.; and, in one instance,[a] as high as 43 lb. The effects experienced by the workmen were pain in the ears, which soon passed away, or was

[a] The amount of pressure was indicated by a gauge inside the cylinder, the indications of which denoted the increase of pressure above that of the atmosphere at 15 lb. thus, an indication of 28 lb. on the gauge would represent a total pressure of 43 lb.—viz. 28 lb. + 15 lb. weight of atmosphere.

relieved by the act of swallowing; headache; increased sense of hearing; anomalous pains in the limbs; occasionally bleeding from the nose; and a feeling of general distress and uneasiness. These symptoms were all much increased when, the air-cocks having been opened to the full extent, the transition from one medium to the other was too rapidly effected. The state of the general health and the previous habits of the workers appeared to exercise considerable influence on the symptoms. These symptoms were felt on first passing into the compressed air, but to a much greater extent on the pressure being removed, on their passage from the cylinder to the external air; and in this stage of the works the serious and fatal[a] effects were produced.

Case I.—On the evening of 3rd October, 1861, Dr. Cuthbert was summoned to visit Denis M'Loughlin, aged 28 years, who had become suddenly ill on reaching the open air from the interior of one of the cylinders. Dr. Browne, of Londonderry, was in attendance, and had requested Dr. Cuthbert's assistance. M'Loughlin, after working for four hours under a pressure of 23 lb. to the square inch, had, on reaching the outer air, suddenly fallen into a state of insensibility. He was at once carried into a shed close at hand, by his fellow workmen, who ineffectually endeavoured to pour some stimulant down his throat. He was lying on his back in a state of total insensibility; the surface of his body cold and livid; eyes nearly closed; right side of face partially paralysed, and the mouth drawn to the opposite side; strabismus of right eye; pupils of natural size, but very sluggishly obeyed the stimulus of light; the pulse at the wrist very weak, fluttering, and irregular, and with difficulty reckoned about 150; first sound of heart almost inaudible; second sound quite so; respirations very irregular, varying from twenty-four to forty-four in the minute; inspiration a very short jerk; expiration prolonged, moaning, and laboured; respiratory murmur heard feebly over every part of the chest with the short inspiration; teeth firmly clenched; no lividity of lips;

[a] Mr. Hughes has informed us that he had no fatal cases at either Rochester or Chepstow, and only one at Saltash, in a man of broken-down health, who died on leaving the cylinder, in which he had been a very short time. At the sinking of the Kaffre Azzyat bridge five Arabs died from effects of pressure—one in the cage, coming out, before he reached the outer air; another became exhausted in the cylinder, and died after passing through the cage; the three others died in a similar way. All were men without stamina. Blood issued from their mouths, noses, and ears. These fatal cases occurred when the pressure was above 30 lb.; the death in the cage was at 36 lb. The men working below did not complain of inconvenience or suffer from accident.

sometimes the mouth moved, and the tongue slightly protruded; when the soles of the feet were briskly rubbed with a coarse towel there were slight muscular movements of the legs. The patient's condition seemed hopeless in the extreme, being a strange compound of those states which we are in the habit of denominating *coma* and *asphyxia*. It was at onee evident that serious mischief had oceurred in the brain, producing the faeial paralysis and deep stupor, and that this mischief had extended to the medulla oblongata and upper part of spinal cord was only too probable; thus implieating an important portion of the respiratory tract, and accounting for the serious respiratory distress. At the same time the heart's aetion was so weak that the pulse at the extremities was almost imperceptible, and the normal second sound was altogether absent. A small quantity of sal volatile was poured down his throat, and the surfaee of his body was briskly rubbed so as to restore the natural warmth, and the lower extremities were immersed in a hot mustard bath. The heat of surface was restored, but no other perceptible improvement was evinced. After much anxious deliberation it was determined to try the effect of a eautious blood-letting, and twelve ounees of blood were slowly taken from the arm (the blood was black, very black, viscid, and treacly). The pulse remained unaltered whilst the blood was flowing; but, as the respiration seemed to become more laboured, when the above quantity had been drawn, it was deemed prudent to desist. An enema, containing two drachms of sulphuric ether and half an ounce of turpentine, was injeeted into the rectum and retained, but no effect whatever was thereby produced upon the pulse or respiration. The man's state underwent no alteration, exeept that the respiratory movements became gradually more feeble, and he sank at six p.m., on the 4th of October, exactly 24 hours after eoming out of the cylinder.

Case II.— —— Carlin was similarly seized about the same time. His condition was so entirely alike that of the previous patient that any minute description of his state is unnecessary. In his case there was no facial paralysis. Strange to say he lived exactly the same length of time as the other patient, viz., 24 hours.

Case III.—October 10, 1861. W. M., aged 23, reported as being seriously ill after working in a cylinder of new bridge; when visited was found much depressed, but quite sensible, complaining of severe pains in his legs and thighs; pains not increased by pressure, but described as being very sharp and shooting. He was quite unable

to walk, and his legs and feet were cold and numb. He was sitting with his feet *almost in the fire*, and several of his toes were considerably burned without his even experiencing the sensation of heat. This man had not been taken ill suddenly, as he had had pains in his legs for some days previously, and it was some hours after coming out of the cylinder that he became so ill as to require medical attendance. The man was put into a warm bed, and given a little brandy, and his legs were briskly rubbed with a stimulating liniment. In two days he was quite well, with the exception of his burned toes, which slowly healed.

CASE IV.—Daniel Doherty, similar case to above; severe pains in legs relieved by stimulating liniments. This man had hemoptysis some short time afterwards, but is now quite well.

CASE V.—James M'Nulty, aged 18, went to work in the cylinder on the morning of 3rd October, 1861. After being four hours under pressure, on coming out of the cylinder into the air lock, and whilst the pressure was being lessened, he fell helpless. He was visited immediately, and was found lying in a semi-comatose condition, able to answer questions on being roused, but speedily relapsing into a state of insensibility. The comatose symptoms passed off in about 18 hours, when he was found to be totally paralysed from the fourth rib, to have retention of urine, loss of sensation, and all the usual symptoms which accompany the worst form of injury of the spine in the cervical region. He was next day removed to the County Infirmary, where he remained till his death, on the 17th of March, 1862, having been in hospital 160 days; sensation or the power of motion never were restored. For a long period before his death he had incontinence of urine and feces, and died exhausted from the effects of universal bed sores.

CASE VI.—John Murray, aged 30, admitted to infirmary with precisely similar symptoms as in M'Nulty's case, with the exception that the paralysis and loss of sensation did not extend above the 8th dorsal vertebra. He lived 30 days, and died from the effects of bed sores so often seen in spinal injuries.

He was a man of weak constitution and of irregular habits.

These are notes of four fatal cases, and two not fatal. Many cases of slight paralysis and muscular pains, and other anomalous nervous affections, came under observation, but it is unnecessary to enter into the particulars of each case.

It is much to be regretted that we were unable to have a *post mortem* examination on any of the cases, and we freely admit that the interest attached to them is much lessened thereby. It may seem out of place to offer any opinion as to the cause or nature of the symptoms in the absence of so essential an element to the full understanding of the subject. We may, however, hazard a speculation which may be taken for what it is worth.

It seems clear that in all the cases the nervous system was chiefly and primarily implicated. The idea of any noxious element in the condensed air, which has been broached by some, must be abandoned, as the workers[a] suffered no inconvenience during their stay (from three to four hours) in the cylinder; all the cases of serious illness occurred on the removal, more or less sudden, of an excess of pressure. It seems reasonable, in the absence of any other cause, to suppose that this sudden transition from a condensed to an ordinary atmosphere gave rise to the serious and fatal injuries we have recorded. Why should this sudden change so remarkably affect the nervous system? It seems to us that what under ordinary circumstances is the protection of the nervous system from injury and accident, becomes in these cases a cause of danger and fatal disease. The brain and spinal cord, encased as they are in bony cavities, and having their vascular supply conveyed through vessels similarly encased, cannot yield to alternating rates of pressure with the same facility as parts of a more elastic and pliant nature. Hence the brain, working together with the other parts of the body under excessive pressure, cannot, when the pressure is removed from the surface, accommodate itself to the altered circumstances so rapidly as other organs; the excess of pressure on the brain and spinal cord must pass off by the narrow passages in which the blood is carried to and returned from the brain and nervous system generally. The bony canals in which the vessels are enclosed render this process a tedious one, and the excessive pressure has, therefore, a tendency to expend itself on some of the delicate structures of the brain or cord, causing rupture of smaller vessels or other analogous injury, and thus producing the fatal catalogue of symptoms which ended in the deaths of the four workmen, whose cases we have above recorded.

[a] That there was no excess of carbonic acid gas was evident from the fact that the candles in the cylinders burned with increased brilliancy. Hens, dogs, and rabbits, were kept at the bottom of the cylinder for many hours without any symptom of suffering or injury.